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INSECTS AFFECTING STORED FOOD PRODUCTS

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CONTENTS

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E. G. LINSLEY[2] AND A. E. MICHELBACHER[3]

THIS BULLETIN is intended to provide the farmer as well as the city householder with information regarding the habits and control of the more important insects attacking stored food products in California. Emphasis has been placed upon those pests which infest foodstuffs that are kept in a dry state, especially grains, beans, peas, nuts, dried fruits, and various cereals and cereal products. With very few exceptions, the insects associated with meats, cheese, and various liquid or very moist foods have been omitted, as have general household pests such as cockroaches, silverfish, and blowflies.

SOURCES AND MEANS OF INFESTATION

Insects attacking stored food products are very widely distributed both in nature and in the abodes and storehouses of man. In view of their nearly cosmopolitan distribution and ability to live under a wide variety of conditions it is not surprising that they have proved both a nuisance and a source of serious monetary losses. Some of these pests, as, for instance, the rice weevil and the Angoumois grain moth, may infest grain in the field even before harvest; others attack processed food materials wherever they are available. Thus cereals are subject to injury from the time they mature in the field until they are actually consumed by man.

Food products in storage may become infested in a variety of ways. As has been indicated previously, the infestation may actually be initiated in the field. In some cases, insects may fly into buildings from the outside, although this is less apt to occur in a private home than in a warehouse. Frequently, in places where food is stored, the pests migrate into clean materials from infested products which have been overlooked, or from refuse which has collected in crevices in the floor or the walls of storage chambers. Those species which are general feeders can be carried about on other materials than foodstuffs. Drugstore and tobacco beetles, carpet beetles, psocids and mites, may gain access to a home in old furniture, rugs, drapes, bedding, and almost any other product of plant or animal origin.

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Materials commonly become infested when placed in contaminated containers, such as sacks which have previously contained infested products. Small amounts of food frequently adhere to the sides and bottoms of trays and boxes used in the transportation of products in bulk. Such particles, though small, may provide enough food material to produce a serious, although incipient, source of infestation.

In the manufacture of such stored products as candy and baked goods, there may be small accumulations of raw products used in processing that settle in secluded places. From these obscure sources general infestations may develop.

Many stored-product pests breed in the nests of rodents, or even in nests of insects, and from these may migrate into homes and other places where foods are kept. Dumps and areas where by-products and waste from processing plants are deposited make excellent breeding places.

One of the commonest sources of trouble in the home is opened food products which have been set aside and forgotten. Any food materials left unprotected for long periods of time are almost certain to become infested by one or several pests. When the product has been wholly or partially consumed, the insects disperse and, where general feeders are involved, every suitable material in the home may become infested. If such an infestation is not eradicated the pests may become so abundant as to literally swarm, and may be found crawling on floors, climbing up walls, and gathering about windows. Further, as the attack continues, secondary organisms follow; and a home, warehouse, or processing plant may become infested with a large number of different species of insects.

Most infestations in the home result from carrying in the pest on some infested product. In order to lessen the danger of transporting insects into the home, every effort should be made to avoid infested products. Infestations are not always easy to detect, but when buying packaged foods broken containers should be refused. Most food products are put up in packages that are insect-tight, and unless the products were infested when originally packed they should remain free of pests. However, some kinds of insects will occasionally bore into packages from the outside.

Insect activity is greatly stimulated by heat; in late spring, summer, and early fall the pest population reaches its peak. Because of this increased activity any unprotected materials are in greater danger of becoming infested at those times; during the remaining portion of the year activity and development are greatly retarded and, except in heated buildings, the danger of infestation is at a minimum.

THE MORE COMMON INSECTS FOUND IN STORED FOODS

A brief account is given below of the more common stored-food insects found in California. The descriptions are nontechnical, designed largely for the layman. Brief comments on control measures accompany the descriptions, but these are more fully discussed in the later section "General Control Measures."

If the reader has difficulty in obtaining materials recommended for control he should consult his local farm advisor regarding possible substitutes or write to the Agricultural Extension Service, University of California, Berkeley.

THE GRANARY WEEVIL

Description.—The adult of the granary weevil, *Sitophilus granarius* (Linn.), is shown in figure 1, *A* and *B;* it is brown to chestnut brown, from 1/8 to 3/16 inch long, narrow, cylindrical, hard-shelled, with a long slender snout. Under a low-power magnification it may be seen that the pronotum (second section of the body) is covered with elongate pits arranged in series and that the wing covers have parallel ridges on them. The larva (grub) is pale in color, with a dark head; it is about 1/8 inch long, fat, curved, and legless (fig. 1, *C*). Under low magnification the surface appears to be wrinkled. The pupa (fig. 1, *D* and *E*) looks somewhat like the adult beetle with the head turned under, the wing covers bent around the body, and the legs and snout pulled up tight against the body. For the first few days it is pale creamy white, but later it becomes brownish.

Importance.—This weevil is one of the oldest known pests of stored grain. It is thought to have come originally from the eastern area of the Mediterranean, but it is now distributed throughout the cooler regions of the world. As a pest it is confined largely to grains, but also feeds on certain other seeds as well as on caked cereals. In California it is the commonest beetle pest of whole grains.

Habits.—The adult bores holes in the grain with its beak; the female deposits an egg in each hole, and then seals it in with a gelatinous material. Under favorable conditions a single weevil may lay more than 200 eggs. The young grubs hatch from a few days to 2 weeks later and feed on the inside of the grain. After 3 or 4 weeks of feeding they pupate and later transform into adult weevils. Under optimum conditions a new generation of weevils may be ready to begin the cycle over again in a month or 6 weeks after the eggs were first laid. They are thus able to produce several generations in a single year and to build up a very large

population in a short time. The weevils do not fly and are wholly dependent upon commerce for distribution and spread of infestation. The adults may usually be seen crawling slowly over or through grain, and when disturbed they will often feign death. When abundant in the pantry

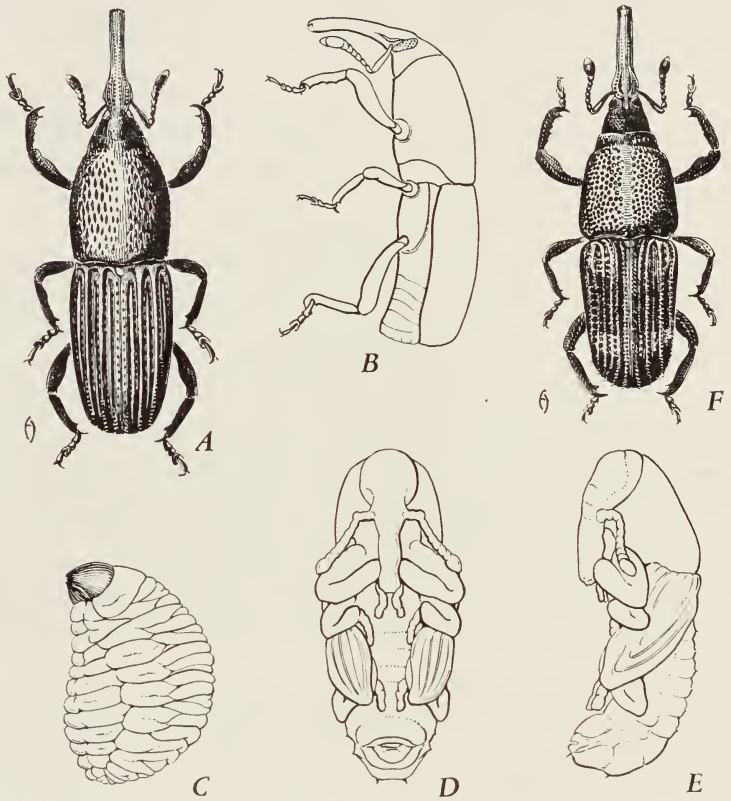

Fig. 1.—*A–E*, The granary weevil, *Sitophilus granarius* (Linn.): *A*, adult; *B*, lateral view of adult; *C*, larva; *D*, ventral view of pupa; *E*, lateral view of pupa. *F*, Adult rice weevil, *S. oryza* (Linn.). (All × 13.5.)

they have a tendency to wander about the house and are then usually noticed for the first time by the housewife.

Control.—In the household the granary weevil may be controlled by locating and destroying the infested materials and by protecting the other food products, suited to the insect, until the infestation has completely died out. This may require a period of 2 or 3 months to accomplish. In storage and in warehouses, fumigation, heat, or cold treatments are usually required.

THE RICE WEEVIL

Description.—The adult of the rice weevil, *Sitophilus oryza* (Linn.), shown in figure 1, *F,* is very similar to the granary weevil, but is a little smaller and usually has four slightly paler areas on the wing covers. Under a low magnification the minute pits on the pronotum appear round and are irregularly arranged. The larva and the pupa are similar to those of the granary weevil (fig. 1, *C, D,* and *E*).

Importance.—The rice weevil has a preference for the warmer regions of the world and is thought to have come originally from India. Like the granary weevil, it is primarily a pest of grains. In California it is much less common than the granary weevil and is less important as a pest.

Habits.—The life history and habits of the rice weevil are rather similar to those of the granary weevil, but the adults are able to fly and are thus capable of speading infestations by their own efforts.

Control.—The control for the rice weevil is the same as for the granary weevil.

THE BEAN WEEVIL

Description.—The adult of the bean weevil, *Acanthoscelides obtectus* (Say), is shown in figure 2, *A;* it is about ⅛ inch long, chunky, squarish, flattened above, and gray or grayish brown with linear pale and dark markings on the wing covers. The head lacks the long beak (fig. 2, *B*) of true weevils, the legs are short and stout, especially the hind pair, and the wing covers are also short and do not completely cover the abdomen. The full-grown larva (fig. 2, *C*) is white, curved, legless, and wrinkled. The pupa (fig. 2, *D*) somewhat resembles the adult beetle but has the head, legs, and wing covers pulled up tight against the underside of the body. When first transformed it is pale in color, but later it becomes darker.

Importance.—The bean weevil is one of the major pests of stored beans because of its ability to breed continuously in storage. It infests nearly all varieties of beans, and less frequently, cowpeas, peas, lentils, and certain other legumes.

Habits.—The adult beetles deposit their minute white eggs near or on the surface of beans. The eggs hatch in from 5 days to 3 weeks, and the larvae enter through a very small hole. They feed internally and complete their growth in from 2 to 6 weeks. They pupate within the bean and are ready to emerge as adults in from 1 to 3 more weeks. The adults cut out a disklike piece from the seed coat of the bean and thus escape to the outside. Under highly favorable conditions they may complete their life cycle in about a month.

Control.—Elimination of the bean weevil from the home may be accomplished by the destruction or protection of stored beans or peas, since the species does not infest grains, cereals, or other stored food products.

In case of heavy infestations, or in warehouses or storage plants, heat, cold, or fumigation treatments offer satisfactory control. Rapid harvesting of beans and storage in clean, dry, tight buildings will do much to prevent infestations from developing.

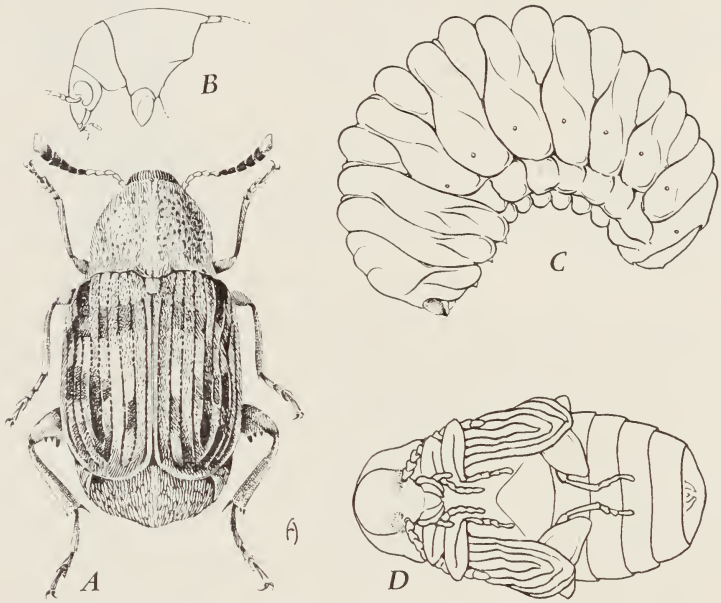

Fig. 2.—The bean weevil, *Acanthoscelides obtectus* (Say): *A*, adult; *B*, lateral view of head and thoracic region; *C*, larva; *D*, pupa. (All × 13.5.)

THE LESSER GRAIN BORER

Description.—The adult of the lesser grain borer, *Rhyzopertha dominica* (Fab.), is shown in figure 3, *A;* it is less than ⅛ inch long, cylindrical, with a somewhat chopped-off appearance at each end. Under a low-power magnification it may be seen that the body is covered with small pits, those on the wing covers being arranged in rows. The larva (fig. 3, *C*) is a small, fat, curved grub, slightly enlarged anteriorly, with short legs. It is less than ⅛ inch long. The pupa (fig. 3, *B*) resembles the adult, with the wings, legs, and antennae held close to the body. It is light in color, but becomes darker shortly before the time for emergence.

Importance.—The lesser grain borer is a serious pest of stored grain in tropical regions. In the United States it is most important in the South. It has caused considerable damage in California but does not appear to be a major pest at the present time. The adults sometimes injure wooden bins and walls of warehouses by boring into the wood.

Habits.—The adult beetles are very active and crawl rapidly over infested materials. They lay their eggs either loosely in grain or attached to the kernels. Several hundred eggs are laid by a single female. The larvae usually hatch in from 1 to 2 weeks and attempt to bore into the

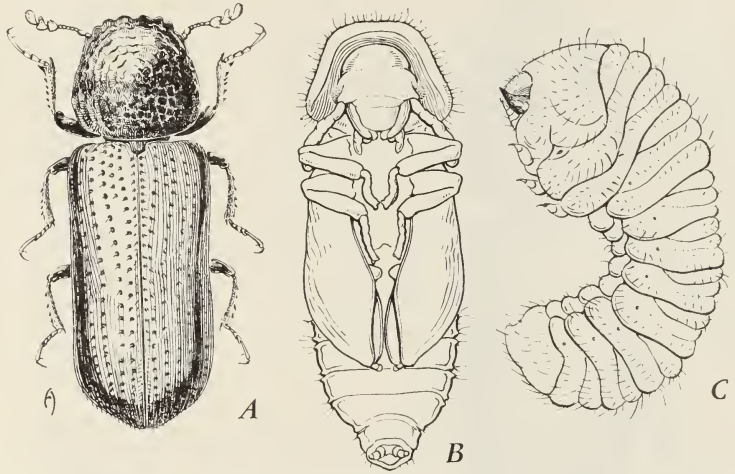

Fig. 3.—The lesser grain borer, *Rhizopertha dominica* (Fab.): *A*, adult; *B*, pupa; *C*, larva. (All × 20.)

grain. If difficulty is encountered, they feed for a while on flour produced by borings of the adults. Eventually they penetrate the grain and complete their development inside. Under favorable conditions there may be several generations a year.

Control.—Wooden structures that have contained infested grain should be fumigated or sprayed in order to kill adults that may have bored their way into them. For further measures see discussion of the granary weevil.

THE CADELLE

Description.—The adult of the cadelle, *Tenebroides mauritanicus* (Linn.), is shown in figure 4, *A;* it is from ¼ to ⅜ inch long, black or dark brown, broad, flattened, with a triangular-shaped head, and with the pronotum well separated from the posterior half of the body. The larva (fig. 4, *B*) is fat, soft-bodied, pale, with a black head and a black

forked tail-piece. It is about 3/8 inch long when fully grown and has a few long coarse hairs scattered over the body.

Importance.—The cadelle is a cosmopolitan species attacking stored grain, shelled nuts, and cereal products. It feeds on grain in both the larval and adult stages, and by moving about from kernel to kernel it does a great deal of damage in a short time. The larvae are also semi-predaceous, feeding to some extent on other grain-infesting insects. In addition to damaging grain, the larvae do appreciable injury to wooden bins and containers, into which they bore before pupation.

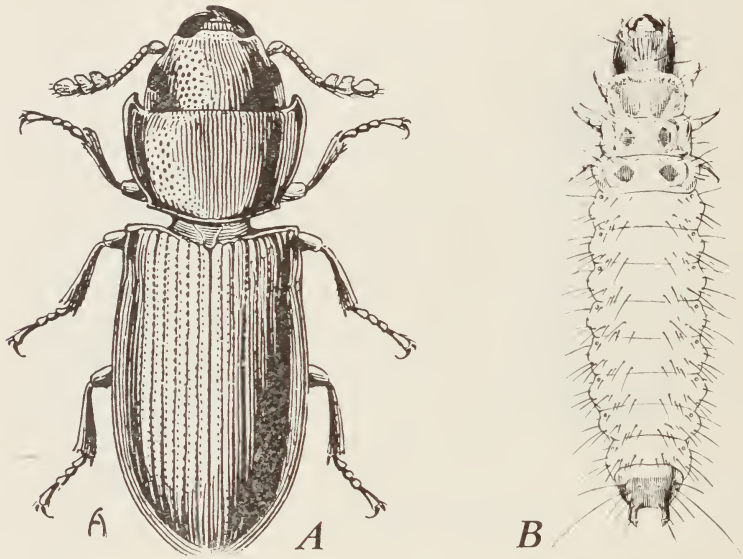

Fig. 4.—The cadelle, *Tenebroides mauritanicus* (Linn.): *A*, adult; *B*, larva. (*A*, × 7.5; *B*, × 3.5.)

Habits.—The adult cadelle is long-lived, and may feed and lay eggs over a period of more than a year. The eggs are laid in batches in the food material and usually hatch in from 1 to 2 weeks. The young larva requires 2 or more months to complete its growth. It then leaves the food and bores into wood, where it constructs a pupal cell. The pupal period requires from 1 to 4 weeks. Both larvae and adults can go for long periods of time without food, and the larval period may be extended over more than a year.

Control.—The control of this insect is the same as for the saw-toothed grain beetle, discussed in the next section. Wooden containers of infested materials, however, should be fumigated or sprayed to kill larvae and pupae which may be present in the wood.

THE SAW-TOOTHED GRAIN BEETLE

Description.—The adult of the saw-toothed grain beetle, *Oryzaephilus surinamensis* (Linn), is shown in figure 5, *A;* it is about ⅛ inch in length, slender, flattened, loosely jointed, hard-shelled, and brown. Under slight magnification the last two segments of the antennae (feelers) appear slightly enlarged and the pronotum has a row of sawlike teeth along the sides and a long shallow depression on each side of the middle. The larva (fig. 5, *D*) is slender, pale in color, with a brownish head, and frequently

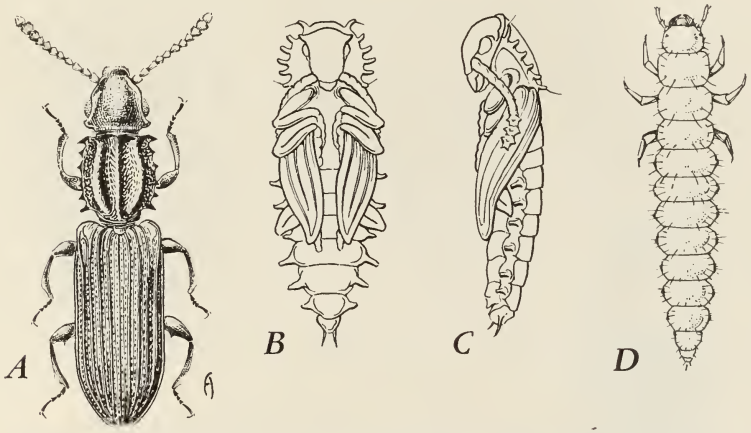

Fig. 5.—The saw-toothed grain beetle, *Oryzaephilus surinamensis* (Linn.): *A*, adult; *B*, pupa, ventral view; *C*, pupa, lateral view; *D*, larva. (All × 15.)

has pale-brownish bands on the body segments. Unlike similar larvae found in stored food products, the posterior end of the body does not have any dark, hard plates or horns. The pupa (fig. 5, *B* and *C*) resembles the adult beetle but is pale (later becoming darker) with the head turned under, the legs pulled up tight, and the wing covers coiled around the body; it also has a row of spines along each side of the body.

Importance.—The saw-toothed grain beetle is one of the commonest and most important of the pests attacking stored food products. Its facility for rapid reproduction, the long life of the adults, its ability to migrate, and its secretive habits are all contributing factors to its importance. It is especially fond of dried fruits, nuts, and sweets, as well as flour, dried biscuits, and cereals.

Habits.—The adult beetles rarely fly but may be seen crawling rapidly over food materials. The eggs are laid in cracks and crevices in the foodstuffs, where they are usually deposited in groups, and require from 3 to 17 days to hatch. Each female may lay several eggs a day and

produce nearly 300 in her lifetime (2 months to a year). The larval stage lasts from 2 to 8 weeks, the length of time depending upon the season. The adults readily bore through paper wrappings and thin cardboard. As a result of their tendency to migrate they are commonly found far from the products in which they breed. The saw-toothed grain beetle is frequently found associated with other stored-products pests.

Control.—In homes the location and destruction of infested materials will usually suffice for control. However, where large amounts of ma-

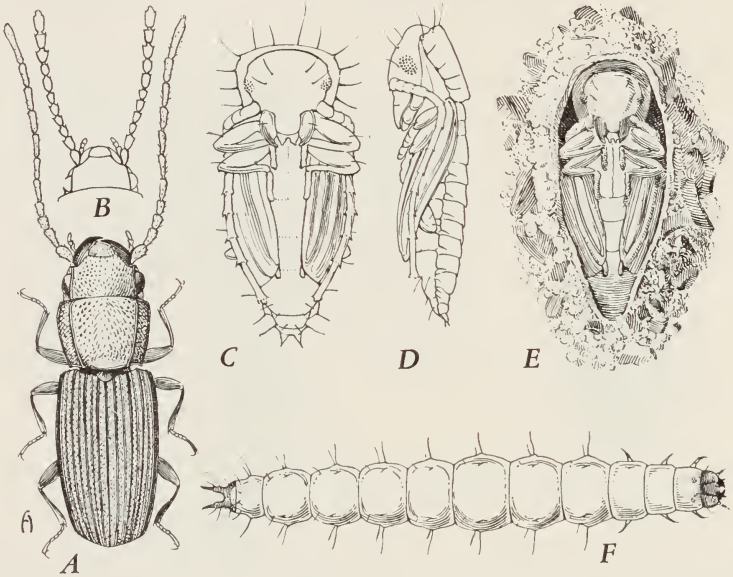

Fig. 6.—The flat grain beetle, *Laemophloeus pusillus* (Schôn.): *A*, adult male; *B*, head and antennae of female; *C*, pupa, ventral view; *D*, pupa, lateral view; *E*, pupa case cut open, showing pupa within; *F*, larva. (All × 19.)

terials are involved, fumigation may be necessary. The safest general fumigant for use with products other than those which have a high oil and fat content, is a mixture of ethylene dichloride and carbon tetrachloride (see p. 42). Methyl bromide is very effective for use in fumigating nuts in quantity but should be used only by qualified persons and where proper equipment is available (see p. 39). Heat can also be utilized in control. Materials in cold storage are well protected.

THE FLAT GRAIN BEETLE

Description.—The adult of the flat grain beetle, *Laemophloeus pusillus* (Schôn.), is shown in figure 6, *A* and *B*; it is one of the smallest beetles (about 1/16 inch long) commonly found in infested foodstuffs.

It is flat, reddish brown, hard-shelled and has long antennae. The antennae of the male are nearly as long as the body; those of the female about half as long. The pronotum is squarish, with a quadrangular depression in the middle and smooth sides, without rows of sawlike teeth. The wing covers have fine, parallel ridges on them. The larva (fig. 6, *F*) is slender, pale in color, with a black head, and has a pair of slender, black, spinelike processes at the posterior end. The pupa (fig. 6, *C*, *D*, and *E*) resembles the adult but is paler, and a little more chunky, with a few coarse hairs scattered over the body; the head and wing covers are bent under and the legs drawn up tight against the body.

Importance.—This species is world-wide in distribution and occurs in cereals and their products, nuts, and dried fruits. However, it is largely a scavenger feeding on debris and dead bodies of insects. It also preys on other insects to some extent. It is seldom found in food which is not already contaminated by other stored-products pests.

Habits.—The female deposits her eggs loosely in flour and other cereal products. The young larvae crawl about through the food material; and, when fully grown, form cocoons within which they pupate and later transform to adults.

Control.—The destruction of infested products, with application of sanitary measures, will usually result in the elimination of this insect.

THE CONFUSED FLOUR BEETLE

Description.—The adult of the confused flour beetle, *Tribolium confusum* Duv. (fig. 7, *A*), is about ⅛ inch long, reddish, or yellowish brown, with short antennae which have the last few segments gradually increasing in size. The pronotum is smooth along the edges, without sawlike teeth. The larva (fig. 7, *B*) is somewhat cylindrical, yellowish brown, with a dark head and a pair of slender, pointed processes at the posterior end. The pupa (fig. 7, *C* and *D*) looks somewhat like the adult beetle, but is pale or white with the head and wing covers turned under and the legs drawn up against the body; the tip of the abdomen has a pair of slender spines similar to those of the larva.

Importance.—The confused flour beetle is probably the commonest pest of cereals and cereal products throughout the world. It is also found in most other stored food materials. Both the larvae and adults feed on the infested materials. Contaminated flour frequently appears pinkish and has a pungent smell.

Habits.—The adult beetles are very active and wander about over a considerable area. They lay their eggs directly in flour and other products. The eggs are sticky, and food particles adhere to them. They

hatch in from a week to 10 days. The larval period is from 2 to 6 weeks, according to the temperature, and the pupal period is from 4 days to a week. Under favorable conditions the life cycle may be completed in 7 weeks, but may require 3 or more months.

Control.—One of the most important factors in the control of the confused flour beetle is sanitation. Even small amounts of flour will

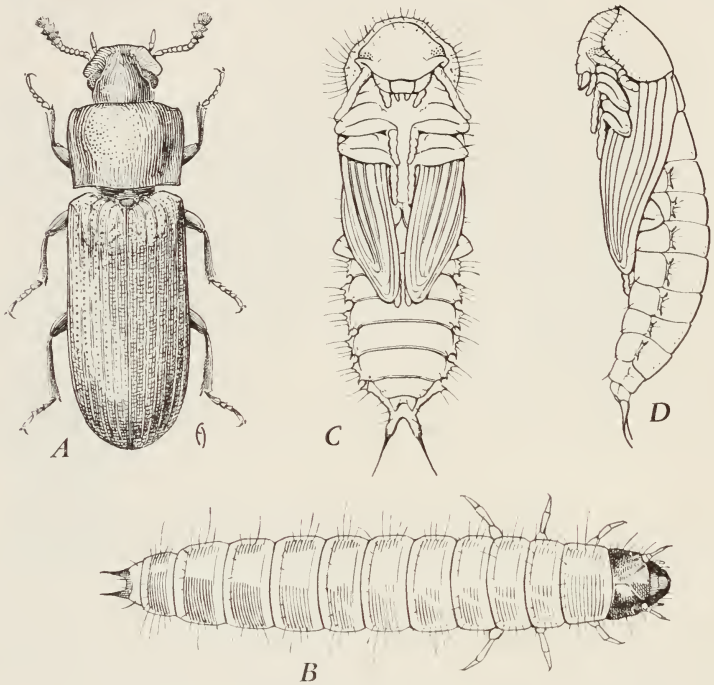

Fig. 7.—The confused flour beetle, *Tribolium confusum* Duv.: *A*, adult; *B*, larva; *C*, pupa, ventral view; *D*, pupa, lateral view. (All × 13.5.)

readily become infested. Heating to a temperature of from 125° to 130° F will kill the pest without injuring the flour. For further control measures see the discussion of the saw-toothed grain beetle.

THE FALSE BLACK FLOUR BEETLE

Description.—The adult of the false black flour beetle, *Aphanotus destructor* (Uttenb.), is shown in figure 8, *A;* it is very similar in general appearance to the confused flour beetle but is slightly larger, usually about ¼ inch long, and is black instead of reddish brown. The larva (fig. 8, *B*) is essentially similar to that of the confused flour beetle.

Importance.—The false flour beetle is a pest of various dog, cat, and rabbit foods, as well as flour, cereals, and similar food products. Both larvae and adults feed on stored food materials.

Habits.—The habits of this beetle are very similar to those of the confused flour beetle. Eggs are laid directly in the food materials. The

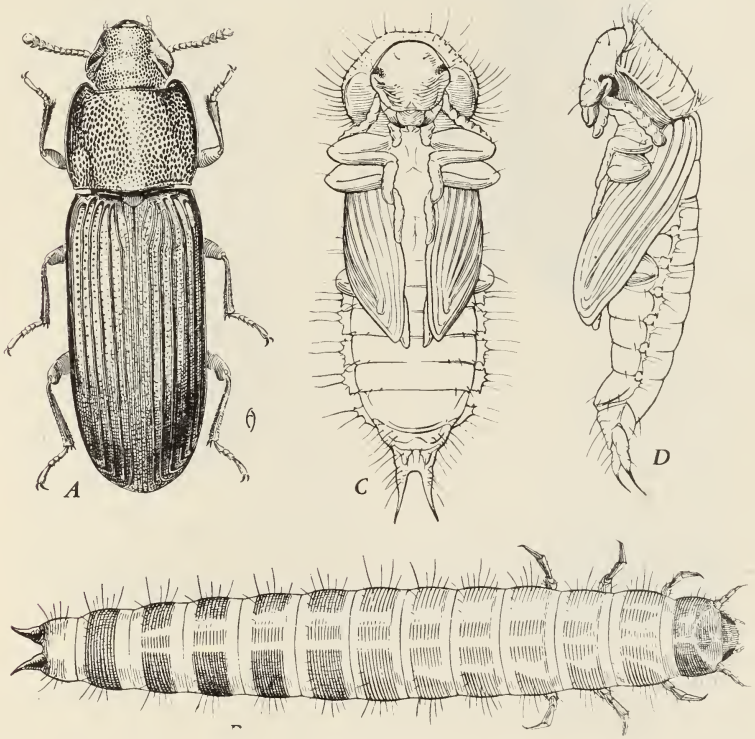

Fig. 8.—The false black flour beetle, *Aphanotus destructor* (Uttenb.): *A*, adult; *B*, larva; *C*, pupa, ventral view; *D*, pupa, lateral view. (All × 11.)

adults are very active and readily crawl about buildings and infest exposed materials.

Control.—The control is the same as for the confused flour beetle.

THE BROAD-HORNED FLOUR BEETLE

Description.—The adult of the broad-horned flour beetle, *Gnathocerus cornutus* (Fabr.), is illustrated in figure 9, *A* and *B;* it resembles the confused flour beetle in size, form, and color, but the wing covers are a little smoother and more shining. The males have large, prominent jaws, and broad flat horns on the side of the head. The larva (fig. 9, *F*)

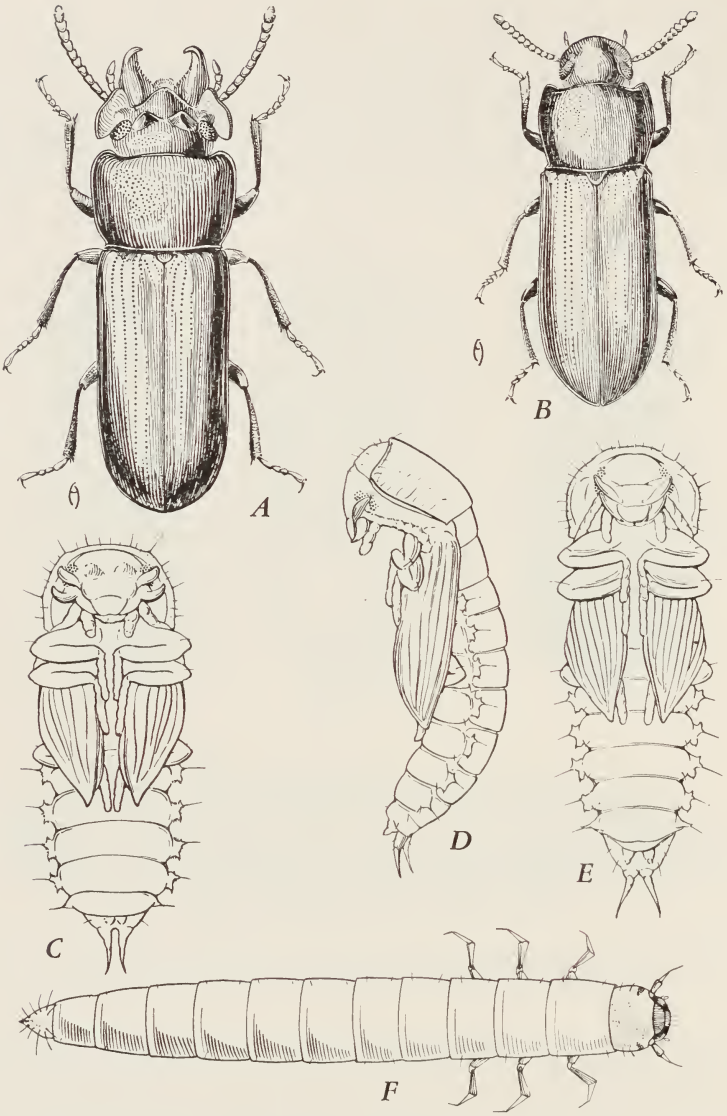

Fig. 9.—The broad-horned flour beetle, *Gnathocerus cornutus* (Fabr.): *A*, adult male; *B*, adult female; *C*, pupa of male, ventral view; *D*, pupa of male, lateral view; *E*, pupa of female, ventral view. (All × 13.)

is similar to that of the confused flour beetle but has only a single point or "tooth" on the tail piece.

Importance.—The broad-horned flour beetle is generally considered a minor pest. It is cosmopolitan in distribution; feeds on cereals and

cereal products, nuts, and coconut meal; and is often associated with other insects. It is only of secondary importance.

Habits.—The female beetle is long-lived and may lay eggs over a period of 8 or 9 months. The eggs are scattered singly through the food and adhere to flour and other food materials. From 100 to 200 eggs may be laid, and they usually hatch in about a week. The larvae complete

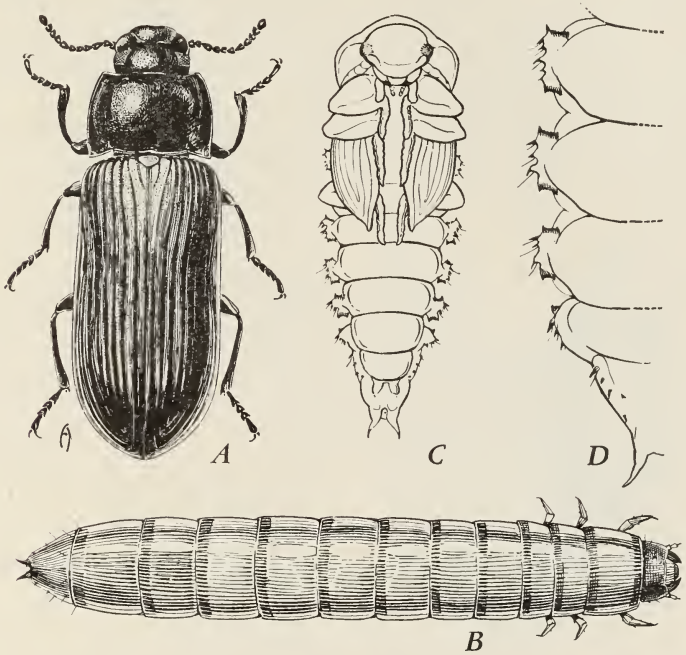

Fig. 10.—The yellow meal worm, *Tenebrio molitor* Linn.: *A*, adult; *B*, larva; *C*, pupa; *D*, lateral margin of abdomen. (*A*, *B*, and *C*, × 4; *D*, × 7.)

their development in from 2 to 6 months. They pupate and transform to adults in a cell made in the food material. The pupal period requires from 2 weeks to a month. Under favorable conditions there may be several generations a year.

Control.—The control is the same as for the confused flour beetle.

THE YELLOW MEAL WORM

Description.—The adult of the yellow meal worm, *Tenebrio molitor* Linn. (fig. 10, *A*), is dark brown or black, and shiny, with fine grooves on the wing covers. It is slightly more than ½ inch long. The larva (fig. 10, *B*) is long, slender, yellowish, with the intersegmental areas lighter

than the segments, giving the body the appearance of having dark rings around it.

Importance.—The yellow meal worm is a cosmopolitan species found in grains and cereals but, although it is a larger species than most others infesting such materials, it is not a serious pest.

Habits.—The adult beetles are nocturnal and fly about only at night. The females may lay as many as 500 eggs during their lifetime. The eggs are laid singly or in small batches. The larvae molt many times and spend nearly a year in the larval stage, after which they pupate and in about 2 weeks transform to adults.

Control.—In the household it is merely necessary to destroy the source of infestation. Sanitary measures should be followed.

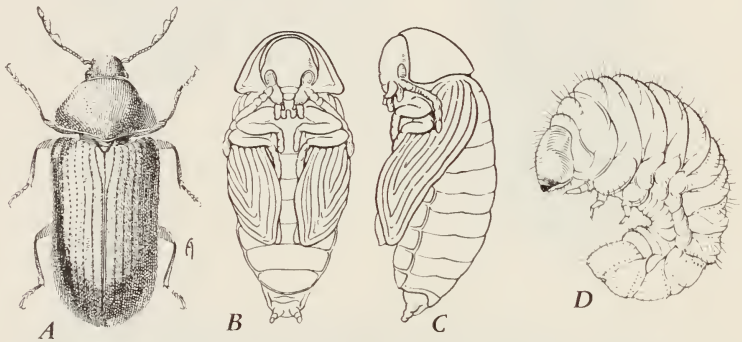

Fig. 11.—The drugstore beetle, *Stegobium paniceum* (Linn.): *A*, adult; *B*, pupa, ventral view; *C*, pupa, lateral view; *D*, larva. (All × 11.6.)

THE DARK MEAL WORM

The adult of the dark meal worm, *Tenebrio obscurus* Fabr., is similar to the yellow meal worm in form and size but is dull pitchy black in color. The larva is also very similar but is a little darker.

The importance, habits, and control of this insect are like those of the yellow meal worm, with which it is commonly associated.

THE DRUGSTORE BEETLE

Description.—The adult of the drugstore beetle, *Stegobium paniceum* (Linn.), is illustrated in figure 11, *A;* it is brown in color, small, cylindrical, and has fine ridges on the wing covers. It is about $\frac{1}{10}$ inch in length. The larva (fig. 11, *D*) is white, small, curved, slightly enlarged at the anterior end, and has short legs. The pupa (fig. 11, *B* and *C*) is similar to the adult but has the legs, wings, and antennae held close to the body.

Importance.—The drugstore beetle is cosmopolitan and is one of the commonest insect pests of stored food products and of drugs in California.

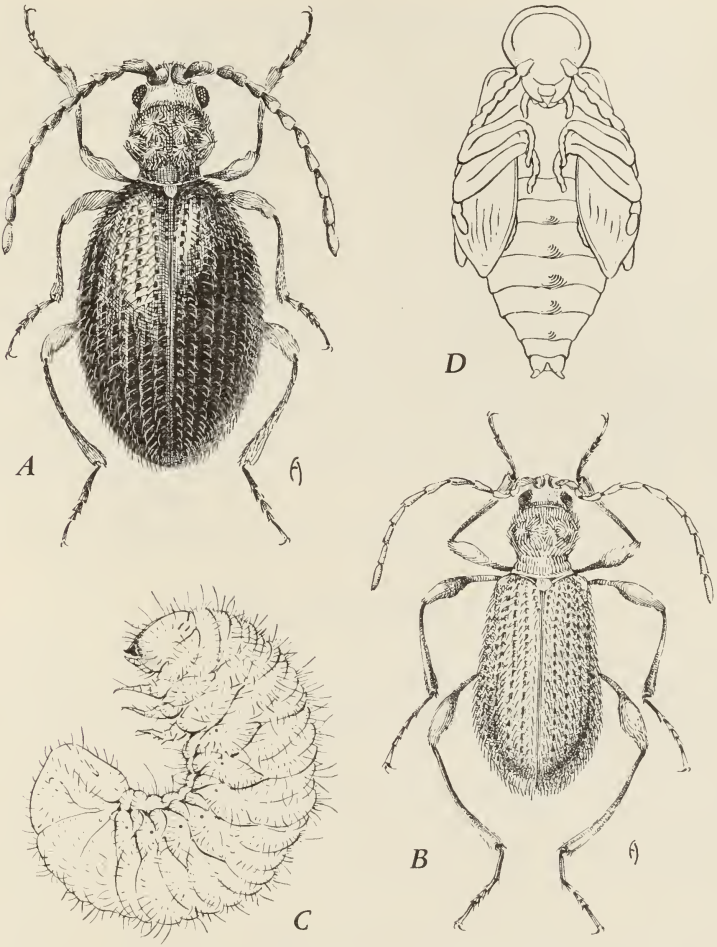

Fig. 12.—The brown spider beetle, *Ptinus hirtellus* Sturm: *A*, adult female; *B*, adult male; *C*, larva; *D*, pupa. (All × 13.5.)

Habits.—The females fly readily and lay their eggs singly in foodstuffs. Several hundred eggs may be laid by a single individual. The young larvae burrow through the food materials and usually require from 2 to 4 months to complete their growth. When full-grown they form small cocoons in which pupation and transformation to the adult stage take place. Under very favorable conditions the entire life cycle may require only 2 months.

Control.—The control measures for this beetle are the same as for the saw-toothed grain beetle.

THE BROWN SPIDER BEETLE

Description.—The adult of the brown spider beetle, *Ptinus hirtellus* Sturm. (fig. 12, *A* and *B*), is a small, spiderlike beetle with large slender legs and antennae. It is uniformly brown in color and about ⅛ inch long. The larva (fig. 12, *C*) is pale in color, small, curved, and resembles that of the drugstore beetle. The pupa (fig. 12, *D*) is rather similar to the adult but has the legs, wings, and antennae held close to the body.

Importance.—The brown spider beetle and various related species are world-wide in distribution and feed in a wide variety of foodstuffs.

Habits.—The females lay their eggs in small batches in the food and may produce as many as a hundred eggs per individual. The larvae burrow through the food material; and when ready to pupate they construct a small oval cocoon either in the food itself or in paper, cardboard, or wooden walls of containers. There may be two or more generations in a year.

Control.—Control is the same as for the confused flour beetle.

THE DRIED-FRUIT BEETLE

Description.—The adult of the dried-fruit beetle, *Carpophilus hemipterus* (Linn.), is illustrated in figure 13, *A;* it is about ⅛ inch long, short, broad, flat, squat, with wing covers which do not entirely cover the abdomen, and antennae which are knobbed at the tip. The color is brown with pale spots. The larva (fig. 13, *B*) is creamy white, with the anterior and posterior ends brownish, and has a pair of pointed processes at the tip of the body. When fully grown it is about ¼ inch long.

Importance.—This beetle is a very important pest of dried fruits, especially those with a high moisture content.

Habits.—The adult beetles may live for as long as a year, and each female lays about 1,000 eggs. The eggs are scattered over the surface of food. When the larvae complete their development they leave the food and, if possible, enter the soil and construct earthen cells in which to pupate. Under very favorable conditions the life cycle may be completed in about 3 weeks. At lower temperatures several months may be necessary.

Control.—Thoroughly dried fruit is in little danger of being attacked. For further control see "The Indian-Meal Moth."

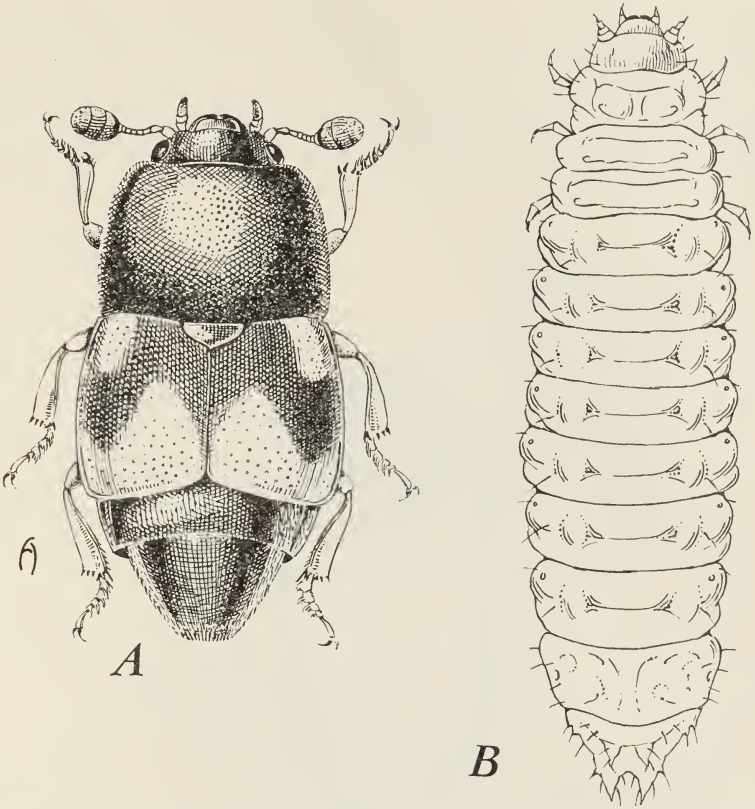

Fig. 13.—The dried-fruit beetle, *Carpophilus hemipterus* (Linn.): *A*, adult; *B*, larva. (Both × 21.)

THE CALIFORNIA FUNGUS BEETLE

Description.—The adult of the California fungus beetle, *Henoticus californicus* Mann. (fig. 14) is elongate-oval, somewhat flattened, and uniformly brownish in color. It is about ⅛ inch long.

Importance.—This species, probably a native of California, has been spread by commerce to many parts of the world. It is primarily a pest of dried fruits but has also been found infesting jams, bread, and even corks. It is a minor pest.

Habits.—The California fungus beetle probably feeds almost entirely on molds and hence is not strictly a pest of stored food products. However, the presence of insects of any kind in food is a source of general annoyance. Little is known of the exact habits of this species; but the eggs are laid on various foodstuffs, and both the larvae and adults feed on molds which are present.

Control.—Infestations by this and related species may be avoided by holding products under such conditions of storage that the quality will be maintained. Usually food materials in good condition are not in danger of attack. Dryness helps to keep the environment unfavorable. For further measures see "The Indian-Meal Moth."

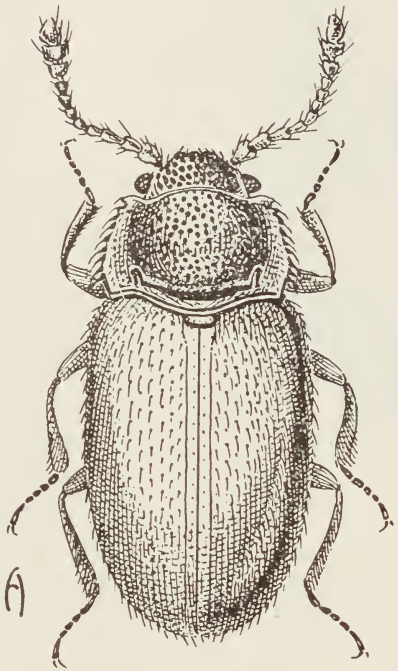

Fig. 14.—The California fungus beetle, *Henoticus californicus* Mann. (× 28.)

THE VARIED CARPET BEETLE

Description.—The adult of the varied carpet beetle, *Anthrenus verbasci* (Linn.), is shown in figure 15, *A;* it is about ⅛ inch long, oval, flattened, with short legs. The wing covers are mottled black, brownish, and white. The larva (fig. 15, *B*) is short, robust, stubby, very hairy, variegated, with a few long tail hairs. The pupa (fig. 15, *C* and *D*) is enclosed in the skin of the larva.

Importance.—The varied carpet beetle is a common household pest of woolens, furs, and other animal products. It sometimes gets into food products that are already infested with some other insect. It is of minor importance as a pest of foods, but such an infestation may spread to other parts of the household and prove serious.

Habits.—The adult beetles lay their eggs loosely in the materials, and the larvae feed upon shed skins of other insects and products of animal origin.

Control.—Sanitation is very important. Where an infestation is general, fumigation may be necessary. For further information see Back (1938).[4]

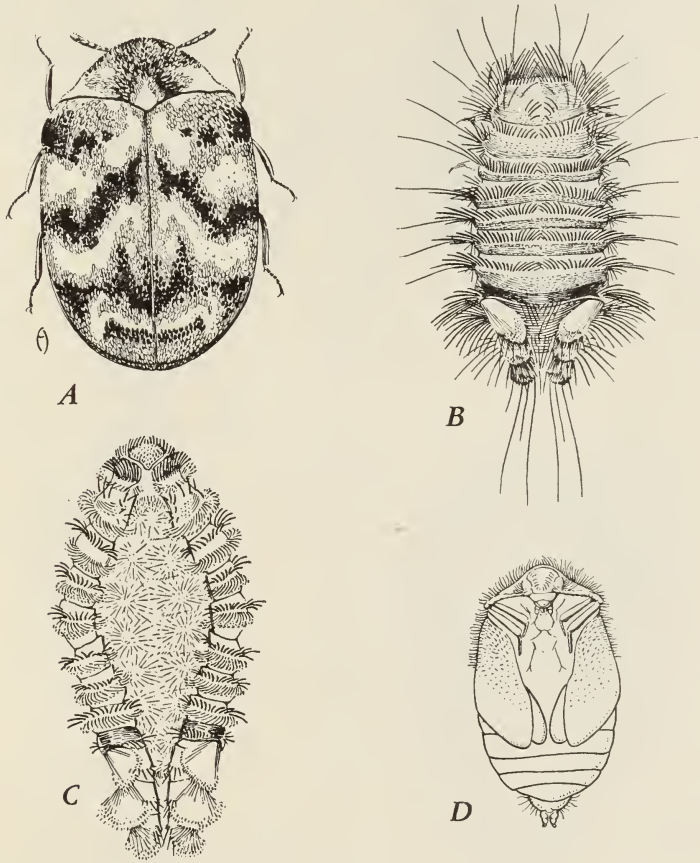

Fig. 15.—The varied carpet beetle, *Anthrenus verbasci* (Linn.): *A*, adult; *B*, larva; *C*, pupa within larval skin; *D*, pupa removed from larval skin. (*A*, ×14; *B*, *C*, and *D*, ×9.)

THE BLACK CARPET BEETLE

The adult of the black carpet beetle, *Attagenus piceus* (Oliv.) (fig. 16, *A*), is similar in form to the varied carpet beetle but is a little larger, about 3/16 inch long, and all black. The larva (fig. 16, *B*) is longer, more

[4] See "Literature Cited" for complete citations, which are referred to in the text by author and date of publication.

narrow, reddish brown above, pale beneath, with a tuft of very long tail hairs.

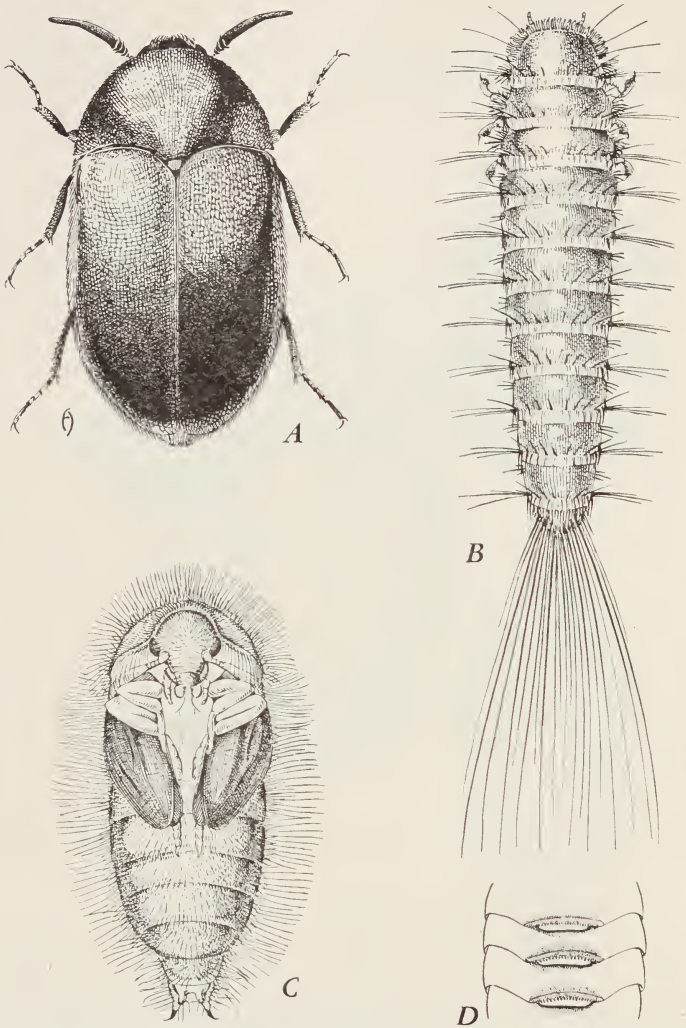

Fig. 16.—The black carpet beetle, *Attagenus piceus* (Oliv.): *A*, adult; *B*, larva; *C*, pupa; *D*, abdominal tergites of pupa. (*A*, × 14; *B*, *C*, and *D*, × 9.)

This insect attacks the same food products as the varied carpet beetle; and its habits, as well as control, are similar.

THE ANGOUMOIS GRAIN MOTH

Description.—The adult of the Angoumois grain moth, *Sitotroga cerealella* (Oliv.), is illustrated in figure 17, *A* and *B;* it is a small, buff

or yellowish-brown moth, with a wing expanse of about ½ inch. The forewings have a few darker markings, while the hind wings are notched at the apical end. The mature larva (fig. 17, *C*) is pale yellowish in color, about ¼ inch in length, with poorly developed abdominal prolegs. The

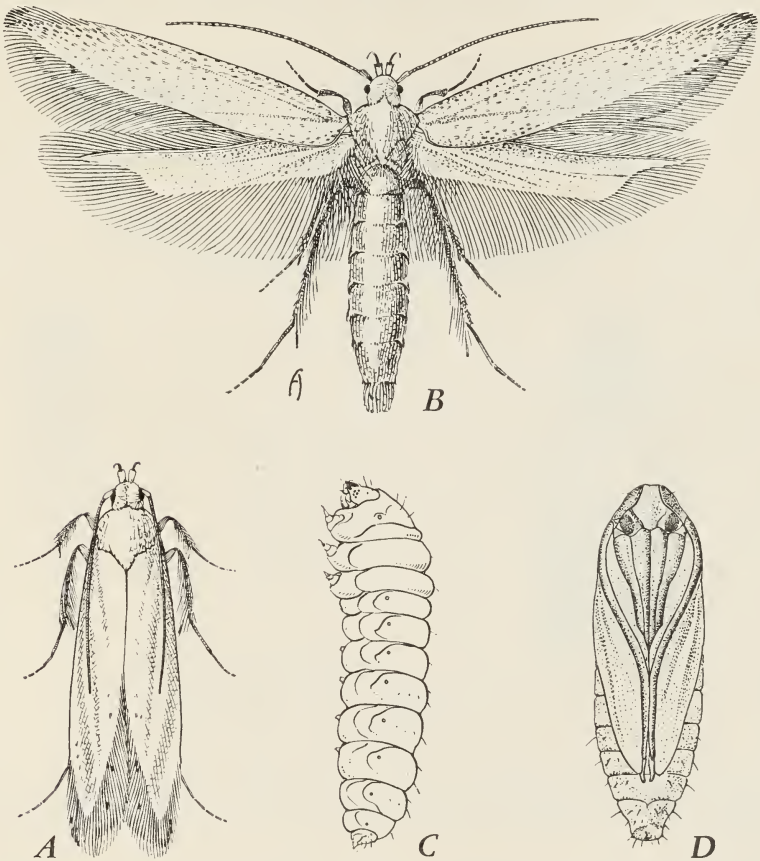

Fig. 17.—The Angoumois grain moth, *Sitotroga cerealella* (Oliv.): *A*, adult in normal resting position; *B*, adult with wings spread; *C*, larva; *D*, pupa. (All × 8.)

pupa (fig. 17, *D*) is light brownish in color, but becomes darker before the moth emerges.

Importance.—The Angoumois grain moth is an important primary pest of grains. It is rather widespread in the United States, where it was introduced from Europe. It is easily killed by cold winters and as a result is a serious pest only in warmer countries. It occurs throughout most of California and is sometimes very destructive where grain harvest is greatly delayed.

Habits.—The moth infests grain both in the field and in storage. The eggs are laid on or near the grain. Upon hatching, the tiny white larvae eat their way into the kernels, where development is completed. Before pupation they bore a tunnel nearly to the outside surface of the seed so that the emerging adults will encounter little difficulty in escaping from the grain.

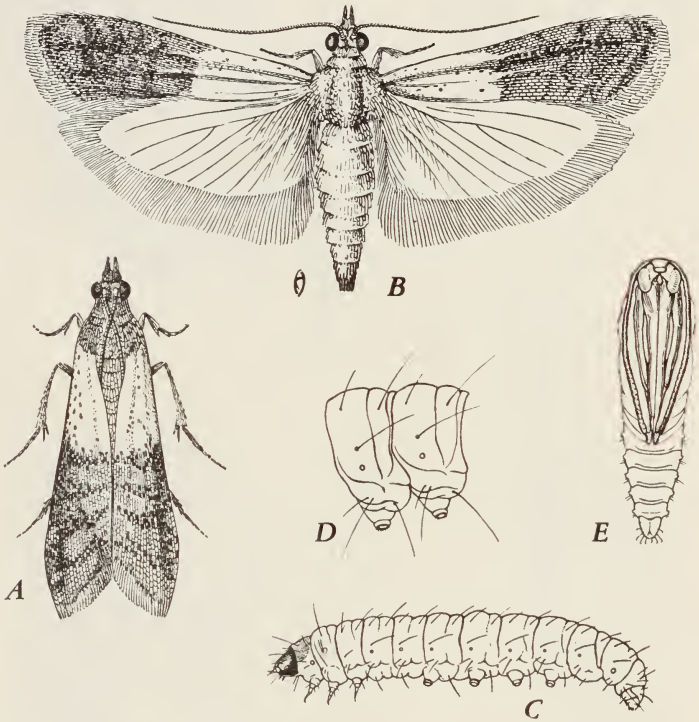

Fig. 18.—The Indian-meal moth, *Plodia interpunctella* Hbn.: *A*, adult in normal resting position; *B*, adult with wings spread; *C*, larva; *D*, enlarged drawing of two segments of the larva in the region of the prolegs; *E*, pupa. (*A*, *B*, *C*, and *E*, × 6; *D*, × 11.)

Control.—In the household it is merely necessary to locate and destroy the infested grain. Since the Angoumois grain moth attacks only whole grain, other grain products are safe. In the field, grain should be harvested as soon as mature, placed in tight clean storage bins, and—if it is heavily infested—fumigated.

THE INDIAN-MEAL MOTH

Description.—The adult of the Indian-meal moth, *Plodia interpunctella* (Hbn.) (fig. 18, *A* and *B*), is very distinctive. It has a wing spread of about ⅝ inch; the outer two thirds of the forewings is coppery

brown, while the basal third is pale gray in color. The hind wings lack distinctive markings and are more or less uniformly gray. The larva (fig. 18, *C, D,* and *E*), which hatches from a small white egg, is about ½ inch long when full-grown, is tan colored, but of a yellowish, pinkish, or greenish tinge; the head and prothoracic shield are dark brown. It is sparsely covered with rather long hairs, and there are no dark spots about the base of the hairs as found in the larvae of the moths (fig. 19, *D*) discussed in following sections. The pupa (fig. 18, *F*) is light brown in color and is found in the silken cocoons spun by the larva. Fragments of frass and food are generally incorporated into the cocoon.

Importance.—The Indian-meal moth is one of the most important insects attacking cereal and cereal products, dried fruits, shelled nuts, chocolate, candies, and various other confections. It is world-wide in distribution. In California, it is the most important moth attacking dried fruits. Because of the fact that it feeds on a wide variety of foods it is also one of the most common moths encountered in the home.

Habits.—The adult moths lay their eggs on any of the materials that may serve as food for the larvae. Under favorable conditions only 4 or 5 weeks are necessary for the insect to complete its development from egg to adult. Like other stored-food pests, it is largely governed by temperature. Under favorable conditions there may be as many as seven or eight generations in a year. Corn is the most seriously attacked of whole grains. Broken grain and that which is infested with primary grain pests also provide a suitable food, and coarser cereal products are preferred to the finer ones. Although the larvae eat their way through the foodstuffs they usually come to the outside to spin their cocoons and pupate. Infested food materials are always full of webbing. When heavy infestations are present the larvae frequently wander away from the infested material and are often found far removed from the original food source.

Control.—In homes, the location and destruction of infested materials should be sufficient if precautions as given under "Sanitation" are followed. Where large amounts of material are involved, fumigation may be necessary. The safest general fumigant to use for products other than those high in oils and fat is a mixture of ethylene dichloride and carbon tetrachloride (see page 42). For amounts that can be placed in a garbage can, carbon disulfide can be rather safely used (see p. 40). For nuts, methyl bromide is a very effective fumigant but should not be used unless proper equipment is available (see p. 39). This fumigant is also widely used in the dried-fruit industry, where many farmers have installations adapted for its use. Materials can also be protected if placed in cold storage.

THE MEDITERRANEAN FLOUR MOTH

Description.—The adult of the Mediterranean flour moth, *Ephestia kühniella* Zell. (fig. 19, *A* and *B*), has a wing spread of about ¾ inch. The forewings are lead gray, speckled with black, or may have transverse wavy black lines. The hind wings are of a lighter gray color. The

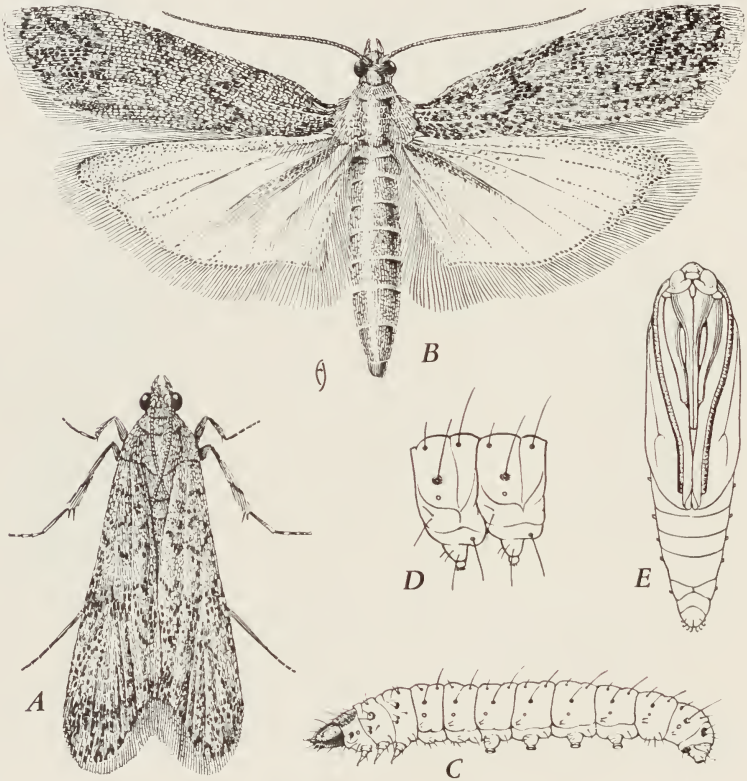

Fig. 19.—The Mediterranean flour moth, *Ephestia kühniella* Zell.: *A*, adult in normal resting position; *B*, adult with wings spread; *C*, larva; *D*, enlarged drawing of two segments of the larva in the region of the prolegs; *E*, pupa. (*A*, *B*, *C*, and *E*, × 4; *D*, × 8.)

larva (fig. 19, *C* and *D*) is about ½ inch long when full-grown, whitish or pinkish in color; and the head and prothoracic shield are brown. It is sparsely covered with rather long hairs, some of which, particularly those in the subdorsal row, have black spots about the base, a character which distinguishes this species from the Indian-meal moth. The pupa is light brown, and is enclosed in a silken cocoon. It is shown without the cocoon in figure 19, *E*.

Importance.—The Mediterranean flour moth is world-wide in distribution and is one of the most troublesome pests of flour mills. Frequently the operation of milling machinery is impeded by webbing and matting of flour caused by the pest. It also attacks other cereal products, shelled nuts, candies, dried fruits, and is one of the common moths found about the home.

Habits.—The moths lay their eggs on or near any product that is subject to infestation. Development is largely governed by temperature, and under some conditions there may be at least four or five generations in a year. The larvae feed throughout the food and leave webbing behind them. Upon the completion of development they crawl to the outside and construct silken cocoons, usually near the infested product. Because the mature larvae may migrate from their food, homeowners are likely to find them in any part of the pantry, kitchen, or even other parts of the house.

Control.—Control is the same as for the Indian-meal moth.

THE FIG MOTH

Description.—The adult of the fig moth, *Ephestia cautella* Walk., is very similar to that of the Mediterranean flour moth but slightly smaller. The color of the forewings varies; most individuals are mottled gray, but others may be strongly suffused with fawn-colored scales. The hind wings are lighter gray in color. The larva also resembles that of the Mediterranean flour moth. When full-grown it is a dirty-white color and tinged with brown or purple.

Importance and Habits.—The fig moth is world-wide in distribution. It is an important pest of dried fruit, although it attacks cereal products, nuts, rice, cocoa beans, cottonseed meal, and probably many other products. Its habits are similar to those of the Mediterranean flour moth.

Control.—Control measures are the same as for the Indian-meal moth. However, since it is principally a pest of dried fruits, provision for fumigation with methyl bromide should be installed where dried fruits are handled in large amounts. All dried fruits should be fumigated for this and other insects before being placed in storage.

THE RAISIN MOTH

Description.—The adult and larva of the raisin moth, *Ephestia figulilella* Greg., are very similar in appearance to those of the Mediterranean flour moth.

Importance.—The raisin moth is one of the most common insects attacking dried fruits. It also feeds on cereal products and probably many other raw materials.

Habits.—The habits of this insect are similar to those of the Mediterranean flour moth. However, it primarily infests fruits on ranches during drying and storage; where fruit is thoroughly dried the danger of infestation is at a minimum.

Control.—Control involves reduction of raisin moths in the field and protection of the drying crop; their abundance may be reduced by elimination of all waste fruits and fruit pits. Fruits dried in the shade under trees and grapes under vines provide especially suitable breeding places, in contrast with fruits or fruit pits exposed to the sun. Mulberries attract this pest; and fruiting trees should either be removed or have their dropped fruits destroyed at 10-day intervals. Since infestation of fruit occurs most frequently on stacked trays and after boxing, covering such materials with tobacco shade cloth will reduce danger of attack. Fruit should also be fumigated before storage; directions for this are given in the section beginning on page 30.

THE CHOCOLATE MOTH

Description.—The adult and larva of the chocolate moth, *Ephestia elutella* (Hbn.), are similar to those of the Mediterranean flour moth. The adult has a wing spread of about ¾ inch. The forewings are brownish gray and are crossed with two oblique lighter-colored lines. The hind wings are of a uniform gray color. The mature larva is about ½ inch long and creamy white. The pupa is light brown, turning nearly black just before the adult emerges.

Importance.—The chocolate moth is widespread throughout the world. It is a general feeder and at times becomes a serious pest. It infests cocoa beans, chocolate, dried fruits, coffee, nuts, cottonseed, spices, tobacco, and cereals.

Habits and Control.—The habits of this moth are similar to those of the Mediterranean flour moth; the control is the same as for the Indian-meal moth.

THE MEAL SNOUT MOTH

Description.—The adult of the meal snout moth, *Pyralis farinalis* Linn., is a beautiful moth with the base and apex of the front wings reddish brown, the middle portion pale, bordered on each side by a wavy white line, and with a row of black dots along the posterior margin. The larva is dirty gray with head and prothoracic shield dark; it is about an inch long when full-grown.

Importance.—This insect feeds on a variety of foodstuffs, especially cereals and cereal products; but it prefers waste materials in damp places, especially hay, straw, and vegetable garbage.

Habits.—The adults deposit their eggs in various vegetable products that are moist or have been held in storage for some time. The larvae spin tubes of silk, enmeshing particles of food material, and feed from the open ends. When ready to pupate they leave the tubes and spin cocoons of silk, covered with food particles and excrement. Under favorable conditions the life cycle is completed in about 2 months.

Control.—Since the meal snout moth requires a damp environment it can be controlled by cleaning up waste materials and keeping storage

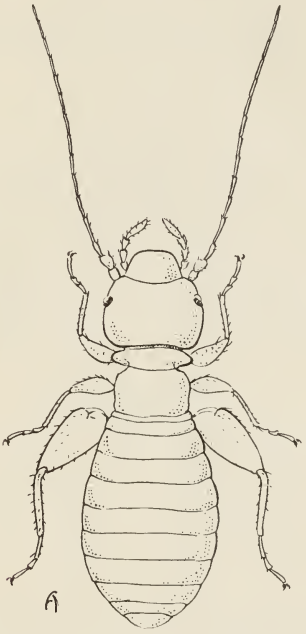

Fig. 20.—The cereal psocid, *Liposcelis divinitorius* (Müll.). (×43.)

units warm and dry. If further control measures are required those recommended for any of the other moths may be used.

THE CEREAL PSOCID

Description.—The cereal psocid, *Liposcelis divinitorius* (Müll.) (fig. 20), is a small, fragile, soft-bodied insect scarcely as large as the head of a pin. It is pale or dark in color, wingless, and feeds on a wide variety of vegetable and animal materials.

Importance.—The cereal psocid is one of the common species found in cereals and their products. The species probably does very little actual damage, but it is annoying because individuals may be present in enormous numbers.

Habits.—Despite their small size, psocids can be recognized by the jerky manner in which they run. The adults lay their eggs about food products; the young individuals resemble the adults. Damp, dark environments are especially favorable for their development.

Control.—Psocids can best be controlled through sanitation measures and by keeping storage locations dry and well ventilated.

THE CEREAL MITE

Description.—The cereal mite, *Tyroglyphus americanus* Banks (fig. 21) is a pale-colored, wingless, smooth, soft-bodied, microscopic animal

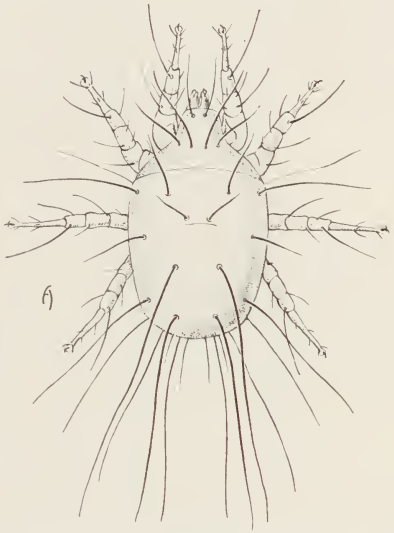

Fig. 21.—The cereal mite, *Tyroglyphus americanus* Banks. (× 93.)

with eight pairs of legs. It is provided with long hairs on the back and legs.

Importance.—These widely distributed mites are frequently found in enormous numbers in cereal and cereal products.

Habits.—When abundant, mites appear as loose, fluffy masses of gray powder, for the cast skins are mingled with the living mites. Moisture favors their development, and when they are found in abundance it is usually a sign that the products on which they are feeding have a higher than normal moisture content. It may also mean that the products are infested with some other stored-product insect. In the home they sometimes swarm from infested material, causing the housewife considerable concern and annoyance. Occasionally they attack humans who handle infested materials, causing a severe dermatitis called "grocers' itch."

Control.—Location and destruction of infested material is the first step in control. Sanitary measures should be followed. Dryness and good ventilation will serve to check the pest. Under conditions where it is possible to do so, heating the infested unit to 130° F for several hours will kill the mites. When grain is involved, screening or fanning may satisfactorily reduce the infestation. Fumigation should not be necessary for control in the household.

GENERAL CONTROL MEASURES

In a preceding section some of the commoner sources of infestation have been pointed out. In order to avoid serious infestations it is necessary that caution be used at all times. Opportunities for materials to become infested are so numerous that there are few homes or other structures where foods are stored that have escaped attack in one form or another. It is therefore no reflection on a housewife if an infestation does develop. The same is true for the merchant, warehouseman, or any other person who has to deal with stored products. Once an infestation has been discovered, however, every effort should be made to control it.

SANITATION

It should be possible to take care of almost any infestation that develops in a home by adopting simple measures of sanitation. In a home, when small amounts of materials are infested, the product should be destroyed immediately. If the infestation is located before the pest starts to migrate and wander about the building, the elimination of the infested product is all that is required. If, however, the insects have begun to migrate, a general clean-up may be necessary. All exposed foodstuffs should be thoroughly examined, and if there is any doubt as to whether or not they are infested they should be destroyed. If the material is of value it may be fumigated or subjected to heat. All remaining uninfested materials should be placed in tight containers, such as jars or tins, with tight-fitting lids. The shelves and floor should be thoroughly cleaned, and all accumulations of foodstuffs behind bins or other objects should be disposed of. Several weeks thereafter, cereals, dried fruits, and similar products should be bought only in quantities that can be quickly used up.

In order to minimize danger of infestation, the following precautions should be followed:

1. Small quantities of food should not be left on shelves. Remnants should be used up or destroyed.

2. All locations where there is any possibility for the accumulation of flour or other food materials should be kept clean. Small amounts of food are all that is necessary for certain pests to live and breed. These sources may furnish individuals for general outbreaks or just enough to be annoying. In bakeries and confectionaries these incipient infestations may provide just enough insects to infest an occasional package.

3. Rooms where baked goods and similar products are allowed to cool should be kept scrupulously clean and made as nearly insect-tight as possible.

4. Old and new lots of materials should never be mixed.

5. Uninfested materials should not be placed in old containers that have not been thoroughly cleaned. Secondhand or returned sacks or other containers should be treated with heat or fumigated before being used again.

6. Avoid the purchase of broken or damaged packages of food products.

7. Units used for the storage of food products should be so constructed that they are tight and easy to clean. Where large amounts of materials are stored they should be built so that they can be superheated or fumigated.

8. Waste and sweepings in processing and conditioning plants should be destroyed. Even when they are placed outside there is danger and likelihood of insects' migrating from them into the storage rooms or units.

9. Keep storage units dry. Moisture favors the development of most storage pests.

TEMPERATURE

Both low and high temperatures can be utilized in the control of storage pests. At a temperature of 40° to 50° F, insect activity ceases, and stored materials free of infestation will remain so. If a product is infested there will be no further development or breeding; and, with a prolonged exposure of one to several months at a temperature of less than 40°, many kinds of stored-product pests are killed.

Exposure to a temperature of from 120° to 130° F for from 2 to 3 hours will kill all stages of stored-product pests. However, it is necessary that the temperature at the center of a package or stack of material should reach the desired heat for the required time if a satisfactory kill is to be obtained. In order to insure the most rapid penetration of heat, the material should be spread out in as thin a layer as possible; small quantities may be sterilized by placing them in an oven. Where an oven is utilized care must be taken not to scorch the product. In many cases an infested product may be freed of insect life by merely turning up

the pilot light on a gas oven. By this method a temperature of from 120° to 130° can be obtained; but in order to allow the heat to penetrate into the center of the material a long exposure is necessary. When a pilot light cannot be utilized, the oven burner should be turned as low as possible without going out. This will usually heat the oven to approximately 180° and will result in a rapid kill. If necessary the oven door can be opened slightly to keep the temperature from rising too high. The product should be stirred from time to time to facilitate rapid penetration of heat. A thermometer should also be used to indicate the temperature.

Because heat is a sure, safe, and efficient means of control, it would seem advisable to equip a storage room so that it can be heated and held at a sufficiently high temperature for a long enough period of time to disinfect the products stored therein. A tightly built isolated room is easily heated by steam or electricity.

SPRAYS

There are several contact sprays that can be used against stored product pests. A water-white, kerosene-pyrethrum spray is probably the best for use in the home. Contact sprays will kill only those insects that are actually hit by the spray. If insects in cracks and crevices are to be contacted by the spray, it is best to use a power sprayer. However, unless there has been a rather serious outbreak it is doubtful whether a spray is necessary in the home. In serious infestations it might be advisable to spray the infested unit after it has been thoroughly cleaned. Sprayed units should always be allowed to air out before being utilized again for bulk material. Since there is a slight fire hazard involved, kerosene-pyrethrum sprays should be used with caution.

For granaries and warehouses, Mackie and Carter (1937) have demonstrated that a 3 per cent oil emulsion or tank-mix oil of 90 seconds (Saybolt) or more, will kill all the insects contacted. They found that sprays could be applied with any orchard sprayer and with a standard spray gun. For thorough work, quantity is needed so that the material will permeate all cracks. The spray should be applied to floors, walls, roofs, and parts underneath and contiguous thereto. In the case of elevator timbers infested with the lesser grain borer, these workers found that the addition of 1 per cent creosote caused the beetles to emerge from their burrows, so that they could be killed. For small units, a 10 per cent oil emulsion spray will provide more satisfactory control. Recent work would seem to indicate that the addition of lethane to such a spray greatly increases its effectiveness.

FUMIGATION

Fumigation for the control of insects attacking stored foods in the home will seldom be necessary if the precautions given in the preceding sections are followed. Where large quantities of foods are stored, fumigation may be desirable when serious infestations develop. If possible, the structures in which such quantities of foods are stored should be constructed tightly so that they can be fumigated. If this is not possible a fumigation vault or chamber should be installed, especially if products are held in storage for long periods of time. These vaults should be built so that the fumigant can be applied from the outside. Unless a person is well acquainted with fumigation procedure, he should call in someone who is qualified to do the work. Many pest-control operators are well equipped to do fumigation.

There are a large number of fumigants available, some of which are much more hazardous to use than others. Among the more important fumigants the following are worthy of mention: hydrocyanic acid, chloropicrin, methyl bromide, carbon disulfide, ethylene oxide, ethylene dichloride, propylene dichloride, carbon tetrachloride, paradichlorobenzene, and naphthalene. These fumigants and their use against insects are more thoroughly discussed by Back and Cotton (1937) and by Cotton (1941).

When a building or storage chamber can be isolated or completely evacuated the following fumigants can be used: hydrocyanic acid, chloropicrin, methyl bromide, or carbon disulfide. If buildings or chambers cannot be completely isolated and where parts of the building are occupied one of the following should be used: mixture of ethylene oxide and carbon dioxide; mixture of ethylene dichloride and carbon tetrachloride; mixture of propylene dichloride and carbon tetrachloride; or carbon tetrachloride.

The fumigants discussed herein are all poisonous and should be used with extreme care.

Fumigation may be carried out in one of several ways. Some of the principal means are as follows:

1. Fumigation of an entire building.
2. Vault fumigation.
3. Bin fumigation.
4. Fumigation under tarpaulins.
5. Vacuum fumigation.

It is unnecessary to discuss these methods in detail here other than to remark that when vacuum fumigation is resorted to, the time of ex-

posure and the amount of fumigant needed are considerably less than are required by other methods. It is a satisfactory procedure in cases where time is an important factor.

The amount of fumigant required and its effectiveness are dependent upon a number of factors:

1. Tightness of fumigation chamber.
2. Temperature.
3. Length of exposure.
4. Method of application.
5. Choice of fumigant.
6. Wind velocity.
7. Type of insect to be controlled.
8. Degree of adsorption and absorption.
9. Penetration.
10. Circulation within the chamber.

Unless the unit to be fumigated can be made nearly gastight, poor control will result. With most of the materials airtightness of the fumigation chamber is absolutely necessary, although with a quick-killing gas like hydrocyanic acid, such lack can be compensated for to some extent by an increase in dosage. Temperature is a very important consideration, since the effectiveness of a fumigant increases with rise in temperature. Most of the available materials require a temperature of at least 70° F, although there are one or two that give satisfactory kills at lower temperatures.

The method of application is worthy of special consideration. For best results the fumigant should be applied to give the highest possible concentration of gas in the shortest period of time. If a large unit is treated a fumigant should be applied at several points; or, if a liquid fumigant is used, a large evaporating surface should be provided.

The choice of fumigant depends upon a number of factors, such as the location of the unit, the nature of the material to be fumigated, possible fire hazard, and the type of insect to be controlled.

There is wide variation in the susceptibility of different insects to fumigation; and it is therefore important to know the kind of insect to be controlled. Among the most difficult to kill are the granary weevils; psocids and some of the moths are more easily killed. With insects that are difficult to kill, one of the more effective fumigants should be used or the dosage of the less effective materials be increased.

Fumigation should be done when there is a minimum of air movement. In a strong wind there is likelihood of the concentration's being reduced within the unit on the windward side.

Adsorption and absorption of the gases are factors which should also be considered. Large amounts of gas may be adsorbed on the surface of some products or absorbed by others, such as flour. The extent of such action is dependent upon the kind and quantity of material to be fumigated in a given space. Larger amounts of fumigants are required where a unit is well filled; and when a highly absorptive material is involved it should be spread out in a thin layer.

Hydrocyanic Acid.—The boiling point of hydrocyanic acid (HCN) is 79° F. This is probably the best all-purpose fumigant, although one of the most hazardous. Its use should be limited to persons who know its dangers and are thoroughly experienced in handling it. When its use is required, the work should be done by a licensed pest-control operator. For best results the unit to be fumigated should be made as nearly airtight as possible. Because of its very toxic nature and the ease with which a high concentration of the gas can be quickly attained it can be used with success even in a loosely constructed unit by increasing the dosage. The gas injures few articles, although it is well to remove liquid foodstuffs. Cheese, dried fruits, and nuts, absorb large amounts of gas, and should be well aired before they are consumed.

Fumigation with hydrocyanic acid may be carried out in four ways: (1) In the pot method the gas is generated in nonmetal pots by placing sodium cyanide in a dilute sulfuric acid solution. The most satisfactory ratio is 1 pound sodium cyanide, 1½ pints sulfuric acid, and 3 pints water. (2) Liquid hydrocyanic acid, obtainable compressed in steel cylinders, can be used by releasing the gas directly from the cylinder into the fumigation unit. Units for fumigation are available equipped with piping systems and nozzles for carrying the fumigant to the desired locations. A small compressor pump can be connected to the cylinder to aid in forcing out the gas and clearing the pipe line following the application. (3) Waferlike discoids are available, consisting of liquid hydrocyanic acid absorbed in some inert material, and sealed in cans. Each discoid contains approximately ½ ounce of liquid hydrocyanic acid, which evaporates on exposure to air. Before opening the cans it is well to precool them with dry ice; this retards the generation of gas and provides greater safety. In order to avoid injury to floor finishings, the discoids should be placed on several thicknesses of paper. (4) Calcium cyanide can be used. This material absorbs moisture upon exposure to air moisture, and chemical action results which liberates hydrocyanide gas. The chemical can be spread out in a thin layer upon sheets of paper; or in grain elevators it may be mixed with the grain as the elevator is being filled.

Fumigation with hydrocyanic acid should not be carried out at a temperature lower than 60° F. The amount of material required is estimated on the amount of hydrocyanide gas actually evolved. The smallest dosage used should be equivalent to at least 8 ounces of hydrocyanic acid to 1,000 cubic feet of chamber space. Where construction is poor, larger amounts must be used. Also the amount and kind of material to be fumigated will influence the dosage to a marked degree.

For complete information on general fumigation with hydrocyanic acid see Back and Cotton (1932, 1937); for its use in the control of insects attacking stored grains and stored foods, Back and Cotton (1936), Mackie and Carter (1937), Shepard (1939), and Cotton (1941); and for the control of weevils in beans and peas see Back (1939).

Chloropicrin.—The boiling point of chloropicrin (CCl_3NO_2) is 233.6° F. This is a very effective fumigant against granary pests. It evaporates slowly, but this disadvantage can be overcome if it is introduced into the fumigating unit as a spray. Evaporation can also be speeded by mixing it with equal parts of carbon tetrachloride. It should be used at a temperature of not less than 70° F and with a minimum of 2 pounds to 1,000 cubic feet of chamber space. There is some evidence that chloropicrin may injure seed, and it also clings to fumigated goods and is not easily dissipated by airing. Fumigation with this material should be attempted only by experienced operators.

For more complete information on fumigation with chloropicrin for the control of cereal pests see Back and Cotton (1936, 1937) and Cotton (1941).

Methyl Bromide.—The boiling point of methyl bromide (CH_3Br) is 40° F. This fumigant is very effective in the control of insects attacking cereals and other stored food products. Investigations by Dudley and associates (1940) have shown that the small amount of methyl bromide or bromide residues that may be left on commercially fumigated dried fruits is not harmful. They pointed out, however, that the use of methyl bromide is inadvisable for more absorptive materials such as milled grains and fatty foods. For satisfactory control, it is necessary that the fumigation unit be nearly airtight.

Methyl bromide may also be used successfully under rubberized or otherwise gasproof tarpaulins. If tarpaulins are utilized the floor should be of tight construction; and if grain is to be fumigated it should not be stacked more than 5 or 6 sacks high. An air dome should be left on top of the stack by placing a couple of sacks endwise to serve as a diffusion chamber. Because of its low boiling point, methyl bromide can be used at lower temperatures than most fumigants. For good control, however,

it is best not to carry on fumigation at a temperature of less than 60° F. Severe poisoning results after prolonged exposure to methyl bromide in concentrations too small to produce an anesthetic action; therefore, its use should be limited to persons who are thoroughly acquainted with its hazards. However, it is a fumigant that is easy to apply and unquestionably will come into wider use for warehouse fumigation. It is not a suitable household fumigant because it degreases furs and reacts with animal proteins to give an odor. The minimum dosage in airtight units is at least 1 pound to 1,000 cubic feet of chamber space. Methyl bromide is a very slow-acting fumigant, at least in the case of some insects, and the final results should not be judged shortly after fumigation. For more complete information on methyl bromide as a fumigant against grain and cereal pests see Mackie (1938), Mackie and Carter (1937), Cotton (1941), and Cotton, Wagner, and Winburn (1941).

Carbon Disulfide.—Carbon disulfide (CS_2) has a boiling point of 115° F. It is one of the best fumigants for use with grains where no fire hazard is involved. It is widely used on farms, especially in grain storage; but it should be handled with caution because of its inflammable and explosive nature when mixed with air. Before applying, one should make certain that its use does not invalidate fire-insurance policies. Fumigation units should be well isolated from other buildings. Carbon disulfide must be kept away from flames and sparks from whatever source. Therefore, fire in any form must not be allowed near a bin or building that is being fumigated. Lighted lanterns, cigars, pipes, cigarettes, sparks from electric switches and motors, or those caused by friction or by hammering upon metal, or even hot steam pipes may cause an explosion of the vapors of carbon disulfide.

Carbon disulfide should be applied evenly over the surface of the stored grain. This should be done as rapidly as possible so that the person handling the material will be exposed to the fumes for a minimum period of time. Small quantities of carbon disulfide can be handled without danger by a person in normal health; but, according to Back and Cotton (1937), persons having heart trouble should take little part in its application. Following application, the bin should be tightly sealed and a warning sign placed on the door. In the absence of a fumigation chamber, infested grain in sacks can be covered with a tarpaulin and fumigated. This should be done on a good tight floor or smooth packed ground. Provision should be made so that there will be an air dome on top of the stack to form a diffusion space for the gas. This can best be accomplished by placing two sacks on edge about 4 feet apart. The tarpaulin should be large enough to allow a 2-foot strip overlap on the

floor about the stack. This overlap should be securely sealed to the floor with weights, and only one side left open. Carbon disulfide may then be poured into pans, and the tarpaulin let down and tightly sealed against the floor surface. Care should be exercised to avoid spilling any of the fumigant on the tarpaulin.

When the homeowner has only a small amount of material to fumigate, this can be done by placing the material in a garbage can out of doors. The required amount of carbon disulfide can be placed in a pan on top of the infested product, the lid replaced and tightly sealed with Scotch or fumigators' tape; or, if these are unavailable, sealed with wet paper.

For satisfactory control it is necessary that the fumigation chamber be tight and that the temperature be at least 65° F. Higher temperatures are desirable because the effectiveness of fumigants increases with the temperature. From 10 to 20 pounds of carbon disulfide should be used to each 1,000 cubic feet of chamber space. If possible the period of exposure should be 24 hours, or longer if time will permit. At the end of this fumigation period the chamber should be opened and ventilated. It is safe to enter as soon as the odor of carbon disulfide is nearly dissipated. For further information on carbon disulfide as a fumigant see Back (1939), Back and Cotton (1936, 1937), Cotton (1938), and Cotton (1941).

The fire hazard can be reduced if carbon disulfide is mixed with carbon tetrachloride at the rate of 4 to 1 by volume, and a small amount of sulfur dioxide is added. A layman should not attempt to mix these materials, however, but should purchase a commercial product. For grain fumigation use 1½ to 3 gallons to each 1,000 bushels, according to the tightness and the size of the unit.

Ethylene Dichloride.—The boiling point of ethylene dichloride (CH_2 Cl CH_2Cl) is 183° F. This is one of the safest fumigants to use. It has a minimum fire hazard, which can be eliminated if it is used at the rate of 3 parts by volume of ethylene dichloride to 1 part of carbon tetrachloride. The odor of ethylene dichloride is not objectionable; and while it has a rather high toxicity to insects, it has a relatively low toxicity to humans. However, a person should wear a gas mask if subjected to the vapors for any considerable period of time. This fumigant evaporates rather slowly, and for best results a large evaporating surface should be provided. It can be placed in large shallow pans on top of the product to be fumigated. Evaporation will be facilitated if a fan is placed so as to blow on the surface of the liquid. A large evaporation surface can also be supplied by soaking rags with the material. The material can

also be sprayed into the chamber. Ethylene dichloride imparts a taste to products having a high oil or fat content, and for this reason it should not be used as a fumigant for such materials. Where there is a fire hazard an ethylene dichloride and carbon tetrachloride mixture is a good substitute for carbon disulfide. Like other fumigants it should be used under as nearly airtight conditions as possible. Fumigation should not be conducted at a temperature of lower than 70° F. The minimum dosage should be 15 pounds to 1,000 cubic feet of chamber space; and, under some conditions, as much as 30 pounds of the mixture is necessary to give satisfactory control. This is probably the safest of the more effective fumigants to use for the treatment of grain on the farm and should be used at the rate of 5 or 6 gallons to 1,000 bushels. For further information on this fumigant see Back and Cotton (1937), Cotton (1941), and Cotton and Wagner (1941).

Propylene Dichloride.—The boiling point of propylene dichloride (CH_2Cl CH Cl CH_3) is 206° F. This material is similar to ethylene dichloride and has about the same uses. It has a slight fire hazard, but this can be eliminated if it is used at the rate of 9 parts of propylene dichloride to 1 part of carbon tetrachloride. It vaporizes more slowly than ethylene dichloride.

Ethylene Oxide.—This chemical, with the formula $(CH_2)_2O$, has a boiling point of 51.2° F; it is a very effective fumigant where tight fumigation chambers are available. Fire hazard can be eliminated if it is mixed with carbon dioxide at the rate of 1 part by weight of ethylene oxide to 9 parts of carbon dioxide. This material is relatively safe to use as far as humans are concerned. The mixture is obtainable in compressed cylinders and can be expelled from the cylinders directly into the fumigation chamber. For grain fumigation in elevators, ethylene oxide is sometimes mixed with crushed solid carbon dioxide "dry ice" and fed in with the grain. The proportions used are at the rate of 3 pounds of ethylene oxide and 30 pounds of dry ice to 1,000 bushels of grain.

This fumigant is rather easily handled, and leaves no odor or undesirable residue on foodstuffs. It injures the viability of seeds and should not be used for their fumigation. One of its advantages is that it can be used at lower temperatures than most other effective materials. Good results can be obtained where the temperature is as low as 60° F. Ethylene oxide should be used at the rate of at least 2 pounds to 1,000 cubic feet of chamber space. The minimum amount of the ethylene oxide and carbon dioxide mixture (1 to 9) to use is 20 pounds. For more detailed information see Back and Cotton (1936, 1937) and Cotton (1941).

Carbon Tetrachloride.—The boiling point of carbon tetrachloride (CCl_4) is 170° F. This material is not very effective in killing insects. Its main use is for mixing with other materials. It provides no fire hazard, and it is a relatively safe material to use. In the home it can be most easily utilized by placing infested material in a tight container such as a garbage can. The fumigant can be placed in a pan on top of the infested material, and the lid sealed with Scotch or fumigator's tape. It should be used at the rate of 30 pounds to 1,000 cubic feet of chamber space and at a temperature of not less than 65° F.

Paradichlorobenzene.—The boiling point of paradichlorobenzene ($C_6H_4Cl_2$) is high, namely 344° F. This is a crystaline material which can be safely used in a home. It should be kept away from foods, since the odor is readily absorbed, but may be used for insects in clothing or other products of plant and animal origin. Such material may be placed in an airtight container, such as a trunk, and a quantity of the crystals liberally scattered throughout the infested material. The crystals may be placed between layers of paper, although this is not necessary. For good control, infested materials should be subjected to the vapor of paradichlorobenzene for several days, and the temperature should not fall below 70° F. Long exposure to the vapors will do no harm.

Naphthalene.—Naphthalene ($C_{10}H_8$) has a boiling point of 424° F. It is a flaky material, and its use and limitations are about the same as given for paradichlorobenzene. Insects are killed by long exposure to the vapors that are given off. Satisfactory results will be obtained only where nearly airtight containers are used.

SAFETY PRECAUTIONS

1. A fumigant should be handled only by a person who is familiar with its dangers.
2. The fumigation procedure should be carefully worked out in advance.
3. If hazardous materials are to be used, workmen should be supplied with gas masks suited to the material worked with.
4. Breathing air containing the fumigant should be avoided.
5. Fumigated units should be well posted or even guarded if necessary.
6. When dangerous gases are used, windows and chambers should be opened from the outside.
7. All equipment should be tested before fumigation is started.
8. The fumigated units should be well ventilated before people are allowed to enter.

9. Where possible men should work in pairs and their activities be carried out as prearranged.

10. The fumigant should be stored in cool, well-ventilated parts of uninhabited buildings.

11. Fumigation is hazardous work, and everyone on the job must concentrate upon avoiding accidents.

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